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PROGRESS REPORT NORSAR PHASE 3

K. A. Berteussen

Royal Norwegian Council for Scientific and Industrial Research

Prepared for:

Air Force Technical Applications Center
Advanced Research Projects Agency

11 April 1975

NORSAR

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1 st Quarter 1975

Prepared by
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report covers operation and research activities at the Norwegian Seismic Array (NORSAR) in the period 1 January-31 March 1975. Both for the field and data center installations this has been a stable period. The number of visits to the subarrays this quarter is exactly equal to the number of visits first quarter 1974. Two UCSB 360-to-TIP interfaces and a second TIP host interface were installed in January. Two studies of scattering in the crust and upper mantle and one study of scattering in the mantle-core boundary have been finished. A Kirnos vertical broadband instrument has been operated at the

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ABSTRACT

The report covers operation and research activities at the Norwegian Seismic Array (NORSAR) in the period 1 January-31 March 1975. Both for the field and data center installation this has been a stable period. The number of visits to the subarrays this quarter is exactly equal to the number of visits first quarter 1974. Two UCSB 360-to-TIP interfaces and a second TIP host interface were installed in January. Two studies of scattering in the crust and upper mantle and one study of scattering in the mantle-core boundary have been finished. A Kirnos vertical broadband instrument has been operated at the NORSAR subarray 04B over a period of about nine months, and the results from this project are now available.

1. ADMINISTRATION AND ECONOMY

1.1 Personnel

Dr. E.S. Husebye has been granted an NTNF fellowship for a six-month stay at M.I.T. He took up his work at M.I.T. late February. Dr. H. Bungum is leading the research group in Dr. Husebye's absence.

H. Gjøystdal (seismologist) is on leave-of-absence for one year from 15 March.

S. Skribeland (programmerer) resigned 1 March.

Mr. George Purcaru, University of Bucharest, left NORSAR 9 March after one year's stay.

Two new operators, Tom Brurberg and Jan Lundem, were hired as of 1 March.

Project Manager Nils Marås visited Vela Seismological Center in the period 8-13 January. Main topics discussed were ARPAnet and budget for 75-76.

1.2 Economy

Contract proposal with estimated costs for the period 1/7-75-30/9-76 has been sent Eastern Test Range as of 20 February.

Economy Status:

1.	Operations and Maintenance		
	1.1 Data Processing Center	\$138 629	
	1.2 Field Installations	\$ 27 372	
	1.3 Data Communications	\$ 25 447	\$191 448
2.	Research and Development		\$ 11 486
3.	Administration		\$ 24 181
			\$227 115

2. ARRAY MONITORING AND FIELD INSTALLATIONS

The array's field instrumentation performance has been stable and satisfactory throughout the period resulting in normal field maintenance activity. In fact the number of maintenance visits to the subarrays this quarter is exactly equal to first quarter of 1974 (28 visits).

A report on technical details of the NORSAR Analog SP station (NAS) after installation at the NORSAR Maintenance Center (NMC) has been made and is in press. After installation of NAS at NMC there is a 2 pair cable connection available between NMC and the Central Terminal Vault at 04B through 04B05. A communication line from NMC to NORSAR Data Processing Center (NDPC) through 04B turned out to be impossible due to high attenuation on one of the line pairs. Two other possible solutions have been proposed to the Norwegian Telegraph Administration; either of them would decrease the line expenses noticeably compared to a permanent line connection.

2.1 NDPC and NMC Activity

The last investigations on NORSAR field installations aimed at improving parts which performed unsatisfactorily have resulted in the report (NORSAR Internal Report No. 3-74/75): Modification proposals on SLEM and associated equipment. The report was sent to VELA Seismological Center as of 12 March for approval.

At the end of the period sixty SP Line Termination Amplifiers remaining at NMV have been modified for wide range DC offset adjustment. Installations in the field will soon be initiated.

2.2 Field Maintenance

The damaged cables at 10C04,06 were repaired 14 March. In addition to routine maintenance, four remote centering devices for LP mass position and free period adjustment were replaced, and five faults on range switching amplifier/analog-to-digital converter were adjusted.

3. COMPUTER CENTER OPERATION AND DATA PROCESSING

3.1 Data Center Operation

The figures below indicate a fairly 'normal' period of operation. No single incident caused excessive outage of any part of the system. As usual, most outages are accounted for by mains power failures and spikes. The difference in down time between the A and B computer is due to different power supplies in the two computers, the A unit being more vulnerable to mains breaks and spikes than the B unit.

Total DP non-recording time in quarter	41 hrs (1.9%)
SPS down time	7.5 hrs (0.35%)
TOD down or irregular	27 hrs (1.25%)
A computer down	57 hrs (2.6%)
B computer down	5 hrs (0.2%)
Average communication line down time	76 hrs (3.5%)

Trans-Atlantic and London Links: Satisfactory operation.

Two UCSB 360-to-TIP interfaces, and a second TIP host interface were installed in January. After replacement of a faulty oscillator in one of the UCSB units, everything appears to perform satisfactorily.

Approximately 2250 job shop programs were run (exclusive routine).

3.2 Programming Efforts

The following programs were developed in this period:

- a program that plots 3-component long period NORSAR data for up to 22 subarrays
- a program for plotting recorded data from the Kongsberg seismograph station
- an improved program for plotting filtered/unfiltered short/long period data from high/low rate tapes
- a subroutine that converts data from 16 bit gain range to integer fullword format

Also, a program received from SDAC for testing the special IMP interface unit has been improved to be used more flexibly.

3.3 Detection and Event Processing

The Detection Processor system has not been modified in any way in this period. Only minor changes have been implemented in the Event Processor.

3.4 The NORSAR Terminal Interface Message Processor (TIP) ARPANET Connection

Work has been started on the coding and implementation of a Network Control Program for the On-line (DP) system. The NCP will be implemented as a task in the system, and our goal is to have a version running by the end of May, thus enabling us to exchange messages on a test basis with the Communications and Control Processor at SDAC.

Our account at SRI-ARC has now been closed, and we have been transferred to the OFFICE-1 computer. Our use of this Host is of the kind reported earlier in these reports.

4. RESEARCH AND DEVELOPMENT

Two studies of scattering in the crust and upper mantle and one study of scattering in the mantle-core boundary have been finished. A Kirnos vertical broadband instrument has been operated at the NORSAR subarray 04B over a period of about nine months, and the results from this project are now available.

4.1 Wave Scattering Theory in Analysis of P-wave Anomalies at NORSAR and LASA

Observed travel time and amplitude anomalies at the NORSAR and LASA arrays are significantly larger than the measurement errors, and cannot be explained in terms of deterministic crust and upper mantle structural models for the respective siting areas. In this study (Berteussen et al, 1975) the Chernov (1960) theory has been used in modelling the crust and upper mantle as a random medium, and also to estimate to what extent such models can account for the observed anomalies. In Table 1 the basic assumptions underlying the Chernov (1960) theory for acoustical wave propagation in

1. Small velocity variations, $\overline{\mu^2} << 1$
2. Statistically homogeneous
3. Statistically isotropic
4. Gaussian correlation function for index of refraction, $N(r) = e^{-r^2/a^2}$
5. Extent of medium much greater than correlation distance, $L >> a$
6. Large scale inhomogeneities (Fresnel-approximation) $ka >> 1$
7. Rytov (Born) approximation $\frac{\Delta I}{I} << 1$ per wavelength (for the whole medium

Table 1

Basic assumptions underlying the Chernov (1960) theory for acoustical wave propagation in random media.

random media is summarized, while Tables 2 and 3 show the results obtained for the crust and upper mantle under NORSAR and LASA respectively. It is found that the random medium modelling can explain 50 to 60% of the variance of the time and amplitude anomalies at NORSAR. The corresponding results for LASA are 50-60% and 25% respectively. In contrast, reasonable deterministic models cannot account for even 25% of this variance. While the random medium model can provide a satisfactory explanation of the observational data, extensive tests have revealed that the parameters characterizing the random medium cannot be uniquely determined from the data.

DATA		CHERNOV MEDIUM MEASUREMENT			
Configuration	Amp/phase	S.d. of refraction index (%)	Correlation Distance (km)	Extent of Medium (km)	Variance Reduction (%)
1A,1B	P	1.6 *	17	≥ 100	97
2B,3B	P	0.8	12	300	84
1B,7B	P	1.0	16	250	96
4B,5B	P	0.9	18	200	93
1A,6B	P	0.9	25	350	96
1A,1B	A	1.2	14	100	60
2B,3B	A	1.4	15	100	57
1B,7B	A	1.3 *	8	≥ 250	36
4B,5B	A	1.0 *	≥ 25	≥ 250	20
1A,6B	A	1.0 *	17	≥ 150	60
1A,1B-4B	P	0.5	30	≥ 250	71
1A,1B-4B	A	0.9	30	≥ 250	73
1A,1B-7B	P	2.0	60	≥ 250	66
1A,1B-7B	A	0.8	35	≥ 100	60

Table 2

Results obtained in modeling the crust and upper mantle beneath NORSAR as a Chernov medium. An asterisk indicates that the standard deviation of the refractive index corresponds to the lower limit of the extent of the medium.

DATA		CHERNOV MEDIUM MEASUREMENTS			
Configuration	Amp/Phase	S.d. of refraction index (%)	Correlation Distance (km)	Extent of Medium (km)	Variance Reduction (%)
A0,B1,B4	P	0.6 0.3	15	50 150	25
A0,B1,B4	A	3.0 2.0	15	50 150	58
66 instruments (Aki, 1973)	A&P	4.0	10	60	
A,B,C ring (Capon, 1974)	A&P	2.0	12	120	

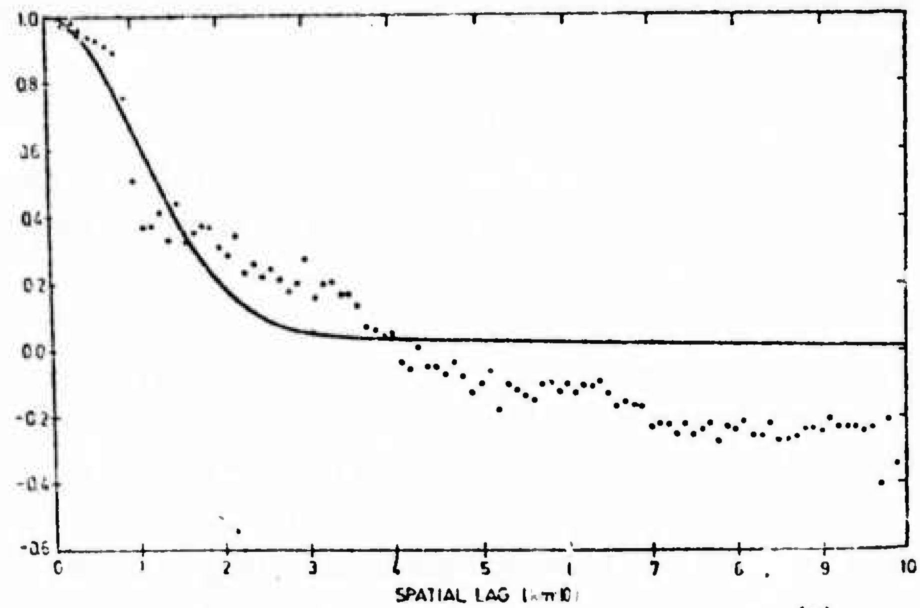
Table 3

Results obtained in modeling the crust and upper mantle beneath LASA as a Chernov random medium. Corresponding results obtained by Aki (1973) and Capon (1974) are also given.

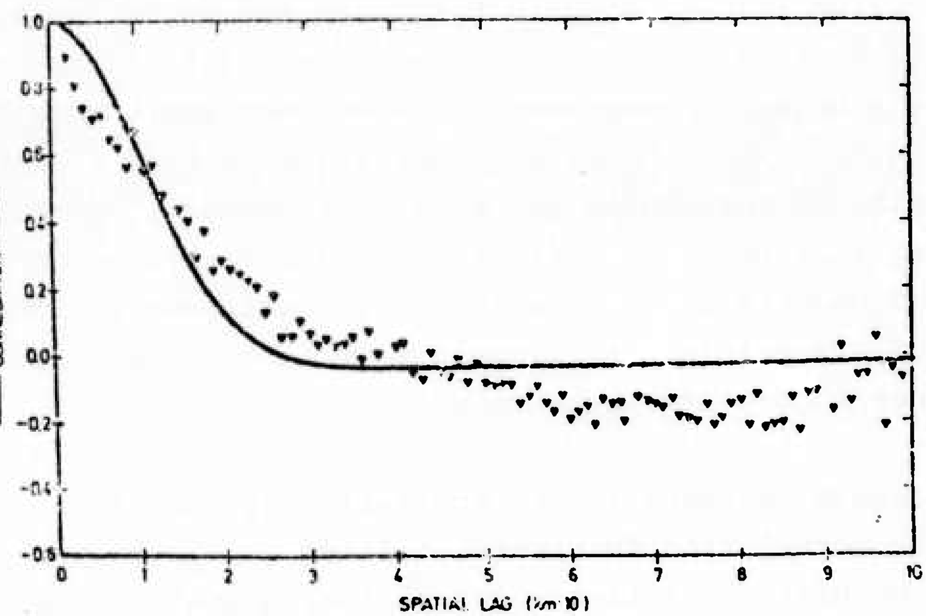
4.2 Time and Amplitude Fluctuations of Teleseismic P-signals at NORSAR in View of Wave Scattering Theory

In the previous study (Berteussen et al. 1975) it was demonstrated that a considerable part of the time and amplitude anomalies observed at the large seismic arrays can be explained using the Chernov (1960) theory for wave propagation in a random medium. In this study (Dahle, 1975a) more emphasis is given to the theoretical aspect of applying this theory and on the validity of doing so. There is limited success with regard to the proposed scattering hypothesis; however, it is believed that the scattering approach deserves considerable attention. Such a conclusion is justified by the fact that the seismic wave field exhibits to a satisfactory degree some of the statistical qualities predicted by the theory. For example, the theory predicts a positive correlation between phase and amplitude anomalies, which also is observed. The assertion of forward wave scattering and mode conversion being basically P→P turns out to be an important point. There is reason to suspect the crust and upper mantle locally being inhomogeneous in a way not pertaining to Chernov's (1960) theory for weak inhomogeneities equally distributed throughout the medium. Stronger inhomogeneities giving rise to back-scattering, conversion to modes other than P and higher order scattering (scattered-scattered waves) are possible explanations of an observed discrepancy between theory and experience.

Substantial support to the scattering hypothesis is provided by the correlation functions depicted in Fig. 1, which shows the correlation of time and amplitude anomalies respectively as a function of spatial lag. These are the features leading to the space predictive procedure described in Quarterly Report no. 3 in 1973. The prediction procedure is important for two reasons. Firstly, because it shows the anomaly percentage explainable by correlated stochastic terms, and, secondly, it provides a means of finding the optimum correlation matrix for the data.



(a)



(b)

Fig. 1 Empirical transverse correlation functions for travel time fluctuations (a) and logamplitude fluctuations (b) together with the theoretical Chernov (1960) functions with correlation distance 15 km and wave parameter 10.

The realization of randomly corrugated seismic wave fronts is undoubtedly important in small aperture array seismology. In this study one has successfully related the fluctuations in body wave travel time, local wave front normal and amplitude to wave scattering in an inhomogeneous crust and upper mantle. A quantitative description of the inhomogeneous medium is inconclusive for the moment, but the results show that attention must be paid to scattering effects when observed times or amplitudes are inverted into structural models.

4.3 Scattering Near the Mantle-Core Boundary

The distribution of slowness, azimuth and amplitude along PKIKP precursor wave trains recorded at NORSAR has been investigated and shown to be fully consistent with that entailed by a theoretical treatment of the scattering of P waves by small-scale random inhomogeneities in the lowest mantle near where P waves enter into and exit from the core. It has been established that the azimuth of arrival of precursor energy can migrate with increasing time from values near to the primary PKP azimuth to values differing from the PKP azimuth by as much as 30°. The migration of peak beam power in both slowness and time is illustrated in the consecutive frames of Fig. 2. The theoretical slowness-azimuth distribution entailed by scattering at the mantle-core boundary is superimposed on this figure, and the agreement between observed and predicted values is remarkably good. These and similar data are particularly strong evidence in support of a scattering interpretation. Furthermore, they discriminate sharply against traditional interpretations involving transition layers within the outer core. Since in addition data previously interpreted as corroborating the existence of sharp reflecting discontinuities within the outer core can be adequately accounted for on the scattering interpretation, there appears to be no seismological evidence which requires distinct layering of the Earth's outer core. This work has been undertaken by E.S. Husebye, R.A.W. Haddon and D.W. King.

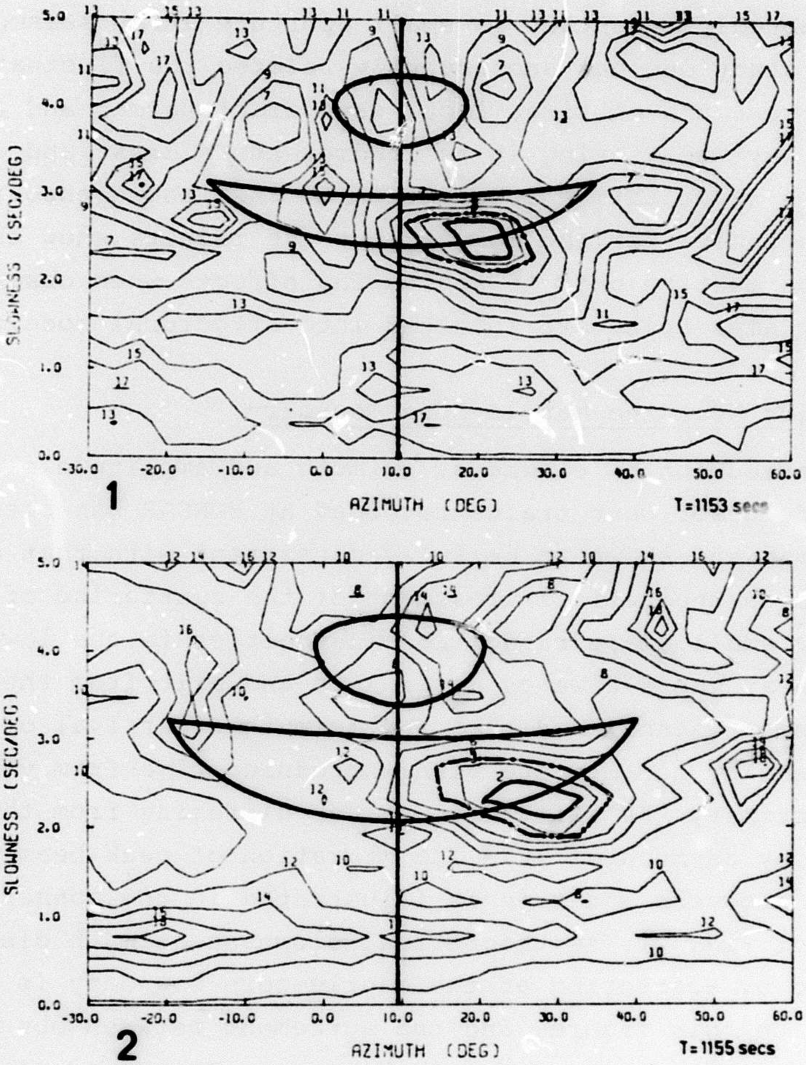
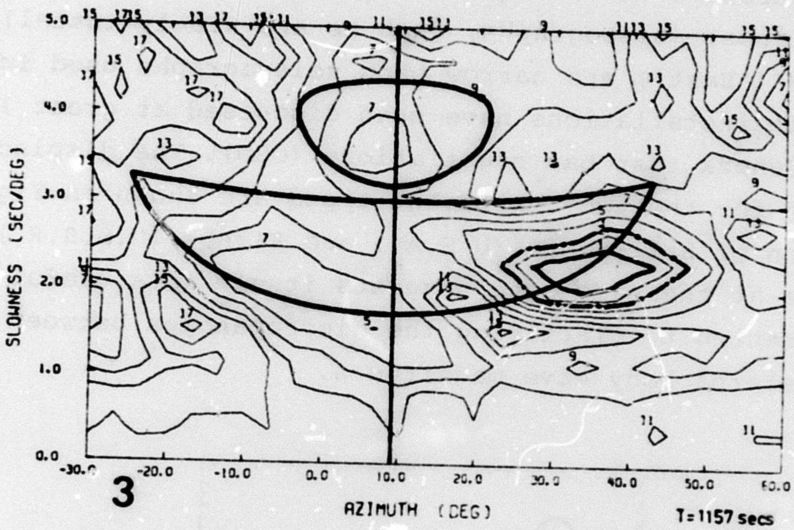
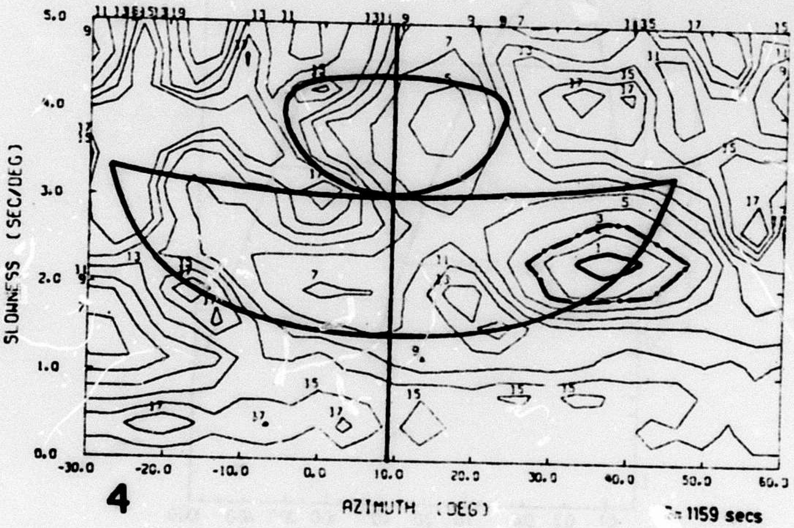


Fig. 2 Contoured beam power levels in slowness-azimuth space for contiguous 2 second intervals of mean corrected travel times as indicated for an event at Δ=135.7°. The contours represent power levels in dB below a maximum of 25.7 dB. Contours enclosing dominant peaks in each frame are darkened. Theoretical slowness-azimuth curves for scattered waves of corresponding travel time are plotted centered on the measured primary PKP azimuth.


SLOWNESS (SEC/DEG)
AZIMUTH (DEG)
T=1157 secs

3


SLOWNESS (SEC/DEG)
AZIMUTH (DEG)
T=1159 secs

4

Fig. 2
(cont.)

4.4 A Kirnos Seismograph in the NORSAR Seismic Array

The differences in earthquake magnitudes measured from wide band (Kirnos) seismographs, such as are widely installed in the USSR ('East') and narrow band seismographs used in 'Western' installations have been discussed at great lengths in the Geneva test ban negotiations (CCD). The displacement response for the two instrument types are shown in Fig. 3. Operation of Hall-Sears (U.S.A.) and Kirnos (U.S.S.R.) seismometers at the same site suggests itself as a useful experiment directed to clarifying the discrepancies between 'Eastern' and 'Western' body wave magnitudes.

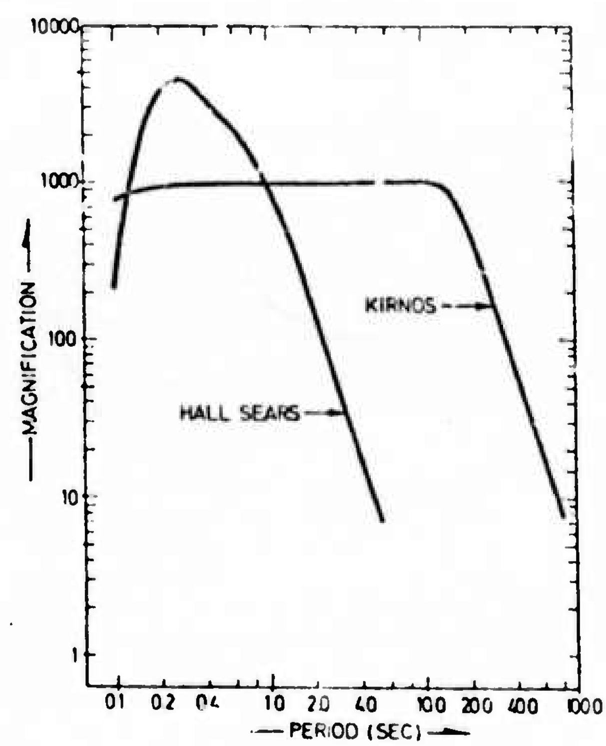


Fig. 3 Displacement response for Kirnos SVK-2 compared to the NORSAR seismometer response (Hall-Sears). Equal magnification at 1 sec period.

As a part of a Nordic project on detection seismology, a Kirnos vertical broadband instrument was installed at NORSAR subarray 04B and operated over a period of about nine months. During the period of operation (Jan-Sep 1974) the seismograms from the Kirnos instrumentation have been read in comparison with the NORSAR bulletin. On an average some twelve events have been identified every month, with more events detected in summer than in winter. Fig. 4 shows the decision histogram together with the maximum likelihood estimated thresholds of 5.7 and 6.4 body wave magnitude for 50 and 90 per cent probability of detection, respectively. All wave modes are included in the detection decision in this case. When only body waves (P, PP, PcP, PKP) are considered, the results are even more modest for the Kirnos seismograph detectability, namely, 5.9 and 6.5. m_b units. However, it has to be pointed out that the reliability of the estimates decreases when sample size is significantly less than one hundred.

Due to poor detectability, the Kirnos seismograph system would need years of operation in Norway in order to establish a reasonable data base suitable for statistical magnitude studies. However, it might be interesting to see if the limited data available follow the general trend that would be expected from a broadband instrument of the SVK-2 type. Due to the paucity of observations, no regionalization was attempted, and, moreover, core phases are excluded from the magnitude considerations in the following. Altogether 25 events in the distance range 18-91 degrees were jointly recorded as P-waves by the Kirnos and the NORSAR Hall-Sears instrument at subarray site 04B00, the two instruments being separated physically by only 2 meters. The body wave magnitude m_b^E computed by the 'Eastern' broadband instrument versus m_b^W computed by the 'Western' SP instrument is shown in Fig. 5. According to Davies (1968), the difference $m_b^E-m_b^W$ should be around 0.5 magnitude units, while Marshall et al (1972) found this

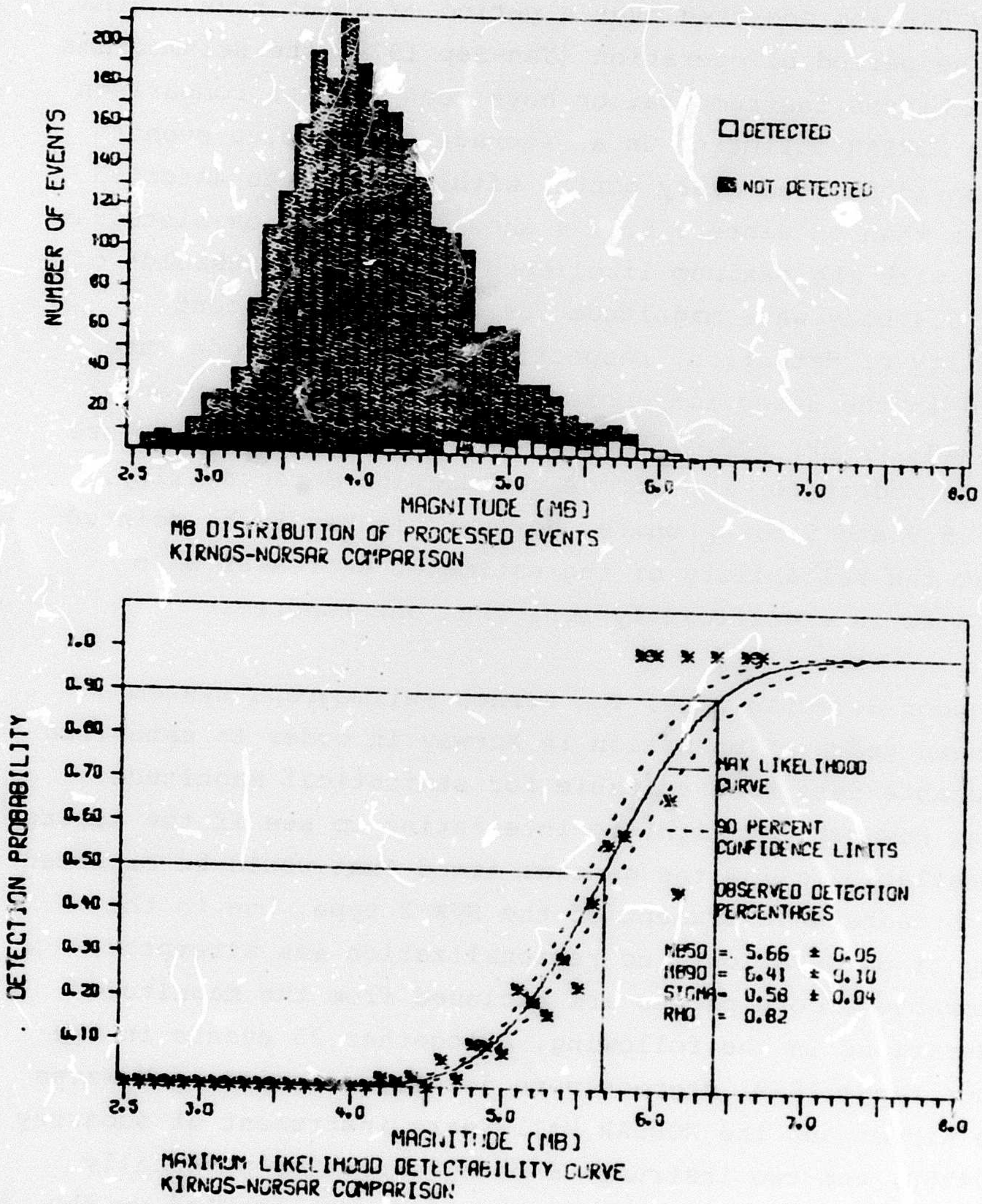


Fig. 4 Kirnos detection statistics for the total number of events identified (all phases included).

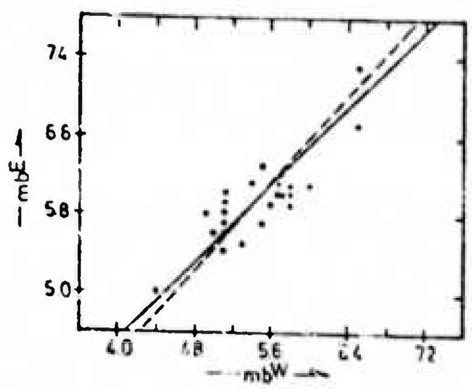


Fig. 5 Kirnos m_b^E versus Hall-Sears m_b^W. Dotted line: 'Eastern'-'Western' magnitude relationship by Marshall et al (1972). Solid line: E-W magnitude relationship by Davies (1968).

relationship to be magnitude dependent, yielding

$$m_b^E = 1.12m_b^W - 0.15$$

Both these curves are given in Fig. 5, and the data is not inconsistent with any of them.

The results obtained in this study support the conclusion that the main cause of the discrepancy between 'Eastern' and 'Western' measurements of magnitude is the difference in frequency responses of the seismographs employed. A rough estimate of the slope b of the frequency-magnitude relationship for the Kirnos gives a much lower value than reported for 'Western' narrowband instrumentation (Richter, 1958; Marshall et al, 1972). Thus by extrapolation, 'Western' data predicts more small shocks and fewer great shocks than 'Eastern' broadband data collected by Kirnos instruments. The Kirnos event detectability is poor, as the noise level imposes a serious limitation on this broadband system. In

conclusion, it should be stressed that in the present context a minimum requirement for a useful broadband seismograph system should include magnetic tape recording to permit such operations as frequency filtering.

More details from this project are to be found in the report of Dahle (1975b).

5. MISCELLANEOUS

5.1 Visiting Scientists

There were no visiting scientists at NORSAR in the reporting period.

5.2 Reports Completed

Berteussen, K.A.: Progress Report, 4th Quarter 1974.

Dahle, A.: A Kirnos Seismograph in the NORSAR Seismic Array, Internal Report No. 4-74/75.

King, D.W., R.A.W. Haddon and E.S. Husebye: Precursors to PP, NORSAR Scientific Report No. 3-74/75.

5.3 Meetings Attended

E.S. Husebye, H. Bungum and H. Gjøystdal participated in the Norwegian Geological Association's winter meeting in Bergen, 7-8 January 1975. The following talks were presented:

Aki, K., A. Christoffersson and E.S. Husebye: Three-dimensional seismic-velocity anomalies in the earth's crust and upper mantle in southeastern Norway.

Aki, K., E.S. Husebye, H. Gjøystdal and H. Bungum: Tectonic movements in the Atlantic north of Iceland - Problems and hypotheses.

Bungum, H., and K. Aki: In situ stress measurements in the NORSAR siting area.

Gjøystdal, H., and E.S. Husebye: Seismic activity in Norway during the time period 1612-1974.

H. Bungum and D.W. King participated in the 'Blue Road Traverse' meeting at the Department of Solid Earth Physics, Uppsala University, 23-25 February 1975. The following talks were presented:

Bungum, H.: Seismicity of the Fennoscandian land uplift area.

King, D.W.: New seismological methods for lithospheric modelling.

5.4 Data Tapes

44 data tapes were sent to Seismic Data Analysis Center, Alexandria, Virginia, in the reporting period.

Two data tapes were sent to Dr. M. Worthington, University of Cambridge, Cambridge, England, in the reporting period.

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